Optimized Asymmetric Quadrature Split Birdcage Coil for Hyperpolarized ^{3}He Lung MRI at 1.5T

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Introduction

Hyperpolarized (HP) ^{3}He imaging requires uniform excitations to make optimal use of available polarization. Too low an excitation angle provides low SNR, while if the angle is too large fast magnetization depletion causes a loss of resolution due to broadening of the point spread function [1]. The objective was to develop an insert body RF coil that maximizes patient comfort while providing uniform B_1 fields and making efficient use of the asymmetric bore space available above the patient bed of a clinical system. Similar asymmetric [2] or non-circular [3] coils are often permanently installed and do not split.

Methods

Geometrical Design: The need to fit inside the proton body transmit coil requires shielding to minimize coil coupling. The positions of the coil's 12 elements and shield shape were designed to produce highly homogeneous B_1 fields using the conformal mapping methods of ref. [3]. Overall inner dimensions are 60 cm length, 50 cm width, and 36 cm height. A photograph of the coil illustrating patient access is shown in **Figure 1**.

Figure 1

Capacitor Optimization: Determining appropriate capacitances required to resonate the coil at the ^{3}He frequency (48.5MHz at 1.5T) with the desired current distribution is a topic of ongoing research [4]. Numerical optimizations are time-consuming and do not provide general insight into the behavior of asymmetric ladder networks, while mesh inductance equalization [5] cannot compensate for mutual inductive coupling beyond that of adjacent meshes. The algebraic method of ref. [4] was applied by first measuring self and mutual inductances of the 12 meshes, followed by inversion of Leifer's expression [6] for the eigenmodes of the coil, under the constraints of tridiagonal capacitor matrix (corresponding to the end-ring structure of the birdcage coil) and (co)sinusoidal modal current distributions. Resulting capacitance values are given in the table; mesh #1 is located at the top of the coil. Lattice matching networks were connected across end-ring capacitors at positions 5 and 8 for quadrature excitation. Network analyzer measurements inside the magnet with a range of subject loading (51 kg, 80 kg, 110 kg) gave the following results: isolation between quadrature ports better than 20dB; match better than 15dB; $Q_{unloaded}/Q_{loaded}$ ratio greater than 2 ($Q_{unloaded}$ = 182).

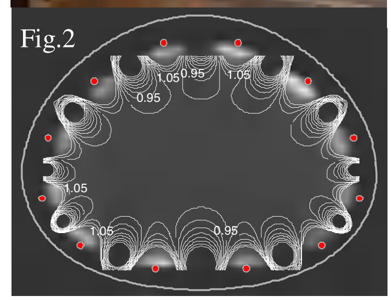

Fig.2

Capacitor	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_{12}	C_{23}	C_{34}	C_{45}	C_{56}	C_{67}
Cap. [pF]	122.5	116.5	125.5	135.5	150.0	120.0	108.0	460	450	1300	∞ (short)	1800	460

Results

Coil and shield were modeled using a method of moments package (NEC2) to confirm the desired resonance behavior and compute B_1 field patterns. **Figure 2** shows locations of shield and elements. Contour plots at 5% intervals of the resulting highly uniform rotating-frame field distribution (B_1^+) in the axial plane are overlaid on the corresponding image acquired from a flood-field phantom (bag filled with 100 mℓ ^{3}He and 100 ℓ N_2) showing excellent agreement with theory. Hyperpolarized ^{3}He MRI was conducted on a 1.5 T system (Philips Eclipse). Gas was polarized to 30% with rubidium spin-exchange apparatus (GE). A 2-D B_1 mapping sequence [7] was used to characterize the coil homogeneity in vivo. Resulting flip angle maps shown in **Figure 3** for equal transmit power settings indicate a consistently stronger B_1 across the lungs with a maximal B_1 inhomogeneity < 5% (b), a vast improvement over the previously used twin saddle coil (a) which displays a 50% variability in B_1. **Figure 4** shows in-vivo images acquired with b) the new coil and a) comparison with the twin saddle coil in the same healthy volunteer using a 3D sequence [8]. Figure 4c) is an example image from a patient with lung cancer.

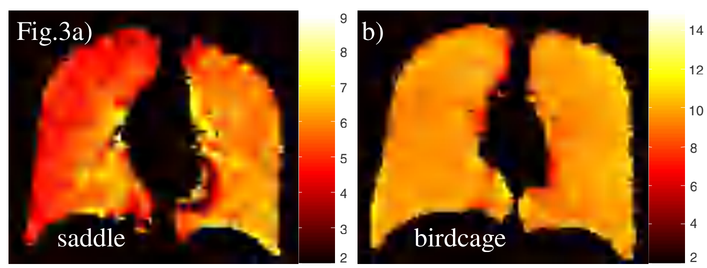

Fig.3a)

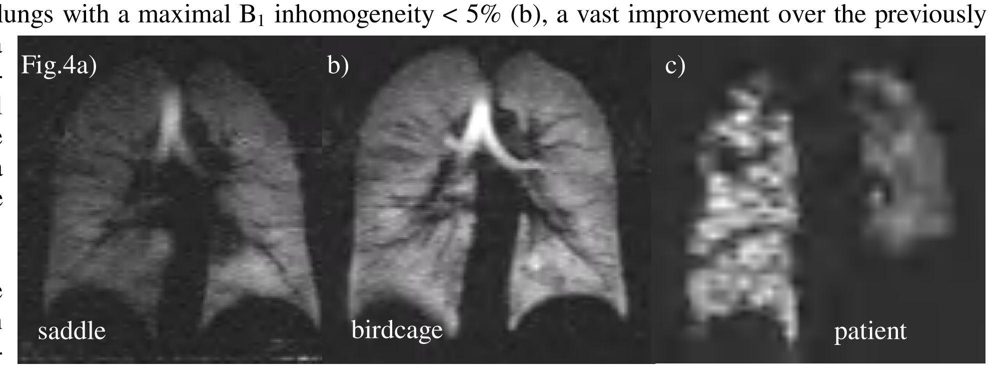

Fig.4a)

Conclusion

A novel whole body asymmetric birdcage is demonstrated for lung imaging with hyperpolarized ^{3}He. The improved B_1 homogeneity of the coil is highly desirable in HP gas MRI where optimal use of polarization is a major challenge. The shielding prevents coupling interactions with the proton body coil and allows efficient quadrature performance. The design is transferable to other nuclei which may require a uniform B_1 over the whole body e.g. HP ^{129}Xe and HP ^{13}C.

References: [1] MRM 47(4): 687-695 [2] ISMRM 2003, #2352; [3] MRM;53(1): 201-211; [4] ESMRMB 2006 #824; [5] ISMRM 1999, #2057; [6] JMR 124(1): 51-60; [7] MRM 53(5): 1055-1064; [8] MRM 52(3): 673-8.

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